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Automated Ground segment for EO constellation: re-imagining spacecraft operations to meet strategic and commercial challenges

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Abstract

In order to meet growing strategic and commercial challenges, EO constellations seem to be the solution that fit the changing landscape. The space segment is evolving rapidly with NewSpace actors, new trends and technologies. It is obvious that the ground segment must adapt and innovate as much to meet these new needs. Increasing the number of operators in proportion to the number of satellites in a constellation is not allowed. The spacecraft control, the Big Data (from the S/C, the Ground control, and the services) and the Image data processing represent an amount of information that only advanced automation and AI can process. This is the challenge for the coming years: automate the ground segment and make it smart to meet an increasingly demanding strategic environment where intel and time are precious. DOMINO-X, co-funded by the space component of the Plan France Relance, initiates the necessary technological and organizational evolutions to meet market expectations by exploiting cloud and Artificial Intelligence with a strong focus on the upstream parts of the ground system: antennas, command and control, data production and management, satellites programming and reprogramming, collection planning… These new technologies that Airbus and its partners are implementing in the next-gen EO ground segment allow us to allocate only 10 operators to control a 10-EO satellites constellation, with full compliance regarding S/C safety and data security and substantial improvement of the "data-access-time". With advanced and centralized monitoring, linked with AI, one operator can easily overview the status of the whole system: Spacecraft (Health status, Flight dynamics, Equipment status…), Coms (Ground stations: local, polar or "As a Service"), Mission (Planning, Follow-up, Availability…), Services (Cloud, Federation…), and infrastructure (Local servers/cloud, workstation). Relevant information from each subsystem are displayed and visible to anyone in the control room. Operators can then access more detailed data regarding specific subsystem from its advanced control workstation. In case of contingency, maintenance, or any non-routine operations the AI (linked to the centralized monitoring) will suggest various actions and recoveries with associated confidence level. The operator has only to confirm and the automation would run its procedure or actions. In a medium-term future, after the AI is trained with Deep Learning, we can imagine the Ground segment to be a "lights-off" center, where the AI(s) and automated systems can run without operator's intervention. Today, Airbus has already developed automated Collision Avoidance Manoeuvre (CAM), automated mission plan uplink, AI-based image production and analysis, and advanced monitoring that already allow us to operate with a limited number of operators. Airbus has always led the market and pushed forward and we are still forward thinking with the next-gen EO ground segment that will allow to meet increasing strategic needs.

Keywords: Earth Observation, Automation, Ground Segment, Constellation

Acronyms/Abbreviations

Very High Resolution (VHR), End-to-End (E2E), Cloud Coverage Notation (CCN), Ground Station As A Service (GSaaS), Control Ground Segment (CGS), Mission Ground Segment (MGS), Image Ground Segment (IGS), User Access Service (UAS), Synthetic-aperture radar (SAR), Payload Data Ground Segment (PDGS)

1. Introduction

Earth Observation systems customers have growing challenges. They need data for their applications and they want to be focused on the downstream part, the value-added data, not how to get the data. Spacecraft operations must be as simple as possible, transparent if possible. However, Spacecraft operation tends to be very complex, more and more complex eventually because of the growing capacities and performances of the satellite systems. Customers

want availability either for commercial applications or defence, data's availability is essential. It is not conceivable to have an off-line system for an extended period of time. Even though our satellites are more and more reliable, the Ground Segment must ensure its part in the End-to-End system reliability. It is obvious that with a constellation, any issue can rapidly be a major one: data from images are ever-increasing and time-demanding to be exploited. The result is fewer operators are available for the upstream part. However, if the upstream fails, there is no more data exploitation in the downstream.

Data availability and therefore system availability, timeliness to get a processed data, system reliability, while increasing its complexity, increasing its possible errors sources (by increasing the number of spacecraft in a constellation), operator turnover… These are the challenges Airbus and its partners addressed. In a few months, with a team of spacecraft operations engineers, Artificial Intelligence researchers, cognitive sciences experts, UX designer and software developers, Airbus and its partners have developed an automated monitoring system for a 10-EO satellites constellation which ease operations and add appeal to operators' work, automate time consuming tasks such as reporting and data validity verification, supercharges contingency identification while minimising risks to ensure an optimal system availability, all together in a modern and competitive work environment.

2. Domino-X: Private-Public Partnership for EO GS

Earth Observation interest is increasing and EO space mission complexity is increasing. The ground segment is a key enabler to these missions. Although types of sensors (optic, SAR…), orbits (SSO, inclined…), number of satellites, ground station (local, polar or GSaaS), level of processing may vary a lot, the ground segments have been always seeing the same architecture broadly speaking. Indeed, from mission to mission we always find similar functions, be it within the command and control domain, the acquisition planning, product processing, advanced processing, supervision, etc.

The implementation of each function changes due to mission specific performance or data, however the broad functions are always recurrent. It is therefore useful to standardise interfaces between certain groups of functions such that integration of the building blocks can be done more easily during production or the operational lifetime of the mission. The technical and industrial philosophy is similar to the Copernicus PDGS architecture, whereby ESA defined interfaces and each vendor delivers its software or service with the agreed upon external interfaces.

DOMINO-X mobilizes large investments by both the French State and industry. The project is led by Airbus and comprises a consortium specialized in various domains and aims at making main interfaces within EO ground systems public and standardized. It is expected that, once the domino interfaces are adopted by the domino suppliers for a given mission the integration, verification and validation activities would be simplified and accelerated. Automating the ground segment and making it smart is also one the biggest challenges for EO Ground Segment for the coming years, along with standardized architecture.

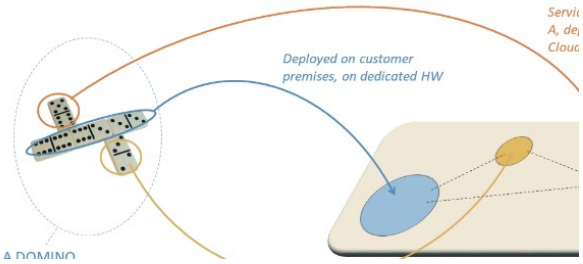

Fig. 1. Schematic view of possible deployment and delivery scheme of dominoes' services

Designing the new Concept of Operations goes through all the details of the control: operators, supervisions, User's Interfaces and room layout. Joining together the extended knowledge of various partners from Space Industry, Cognitive design and UI/UX allows the DOMINO-X project to cover all the aspects of the advanced CONOPS and operations automation.

3. Automation and optimization

Since a few years, everyone gets used to automation. Trust in automation has increased and nowadays we accept letting automated systems perform a large amount of tasks in our everyday life, such as self-driving cars or home automation. Automation is able to ingest a large amount of data and process them rapidly to output a simple analysis, even from complex multi-data sources. This is exactly what Airbus proposes today in its Control Center. With various satellites operated for itself or for its customers, from Toulouse or from the customer premises, Airbus has an extended experience and knowledge in spacecraft operations. Expert in constellations (Pleiades, Pleiades Neo, CO3D soon) Airbus understands the issues of automation in constellations' operations. A few years back, operators had to follow along all satellites visibilities (from local or polar ground stations). Work was repetitive and time-consuming. We cannot conceive the same work with 10 satellites, with complex and heterogeneous payloads (VHR optic, SAR…) and an antenna network (GSaaS). Airbus' ground softwares, which gather command and

control, flight dynamics, scheduler etc, have all been automated so they can perform their task autonomously. Today Airbus is gathering all these automations with a high-level automation and system supervision.

3.1 Automation for monitoring

Modular and scalable architecture, defined within the DOMINO-X project, allows each sub-systems (called domino) to make its own KPI, alerts, output… available to the Technical Monitoring System domino (TMS). Each domino is responsible for its own supervision, but the TMS has the global access to all dominos-provided data. Automation algorithms and Artificial Intelligence can then process data from various dominos and monitor in real time events, understand a contingency or analyze a tendency, an evolution which might lead to a future contingency. This centralization and data analysis automation is a real leap from previous Ground Segments. Before, one operator was required to monitor each sub-system independently. Back then, the only centralized monitoring was for IT services. With DOMINO-X, the whole supervision and monitoring are centralized and automated: IT (workstations, network, cloud…), Mission (targets, mission follow-up, visibilities timeslot…) Spacecraft control (satellites constellation status and availability), high level system KPI… The whole way of interacting with the system has changed, the CONOPS itself has evolved with this new approach. This new CONOPS completely changes operator tasks. The work is eased, more interactive, and allow a better understanding of the whole system instead of repetitive low-level tasks. The Level-1 operator job is completely transformed.

3.2 Automation for reporting

System KPI follow-up is important and necessary. It is therefore necessary to enhance KPI monitoring for the operators. But managers and decision-makers also need reports on their systems. One of the most time-consuming tasks during spacecraft operations is reporting. Enhancing and easing reporting is one of the priorities if we want to make operations more time-efficient. As seen in section 3.1, all data from all sub-systems are accessible by the TMS. The central monitoring can then deliver high level or detailed reports, over a short time-period or over a long-term. The TMS can generate reports automatically (every week or months for instance, based on a specific configuration). Reports can be also on demand, for instance when a critical situation rises and involves an increased targeting over one AOI, a daily mission follow-up with satellites status and availability and antenna network can be a critical input for managers in order to optimize their strategy.

The DOMINO-X architecture, and specifically the data centralization and availability for the TMS, allows fast and automated reports generation. It is another real leap for the CONOPS and for the operators who used to spend too much time consolidating data from various subsystems.

3.2 Centralized supervision

Data centralization, coupled with automation, allows to monitor all sub-systems from a unique workstation. Operators' tasks are completely different from previous systems. It is therefore necessary to rethink the human/machine interaction by taking into account these new inputs. By gathering a team of cognitive sciences experts, UX designer and spacecraft operators, Airbus and its partners have built over their knowledge to build the best solution: the main centralized supervision is the heart of the new control room layout so everyone, from operator to technical manager, can monitor the E2E system at a glance. The main component of the supervision is a display system, which current size is 6mx2m (but it can be adapted to any customer's need or constraint). This display system is connected to the TMS and can display a part of available data from the TMS. The main objective is to allow a complete visualisation at a glance. It is not to have a deep knowledge of all subsystems rather than identifying contingencies sources, following-up high-level mission, and monitoring global system charge.

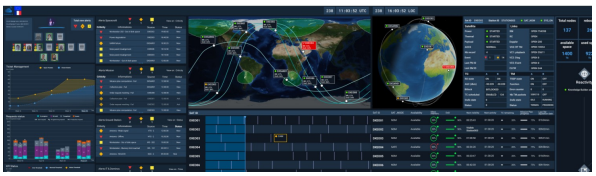

Fig. 2. DOMINO-X central Supervision mockup

This supervision is also coupled to the operator workstations. They have access to the same high-level data, but they can also dig deeper: during a contingency, the supervision display system will not change its configuration (so another operator can continue monitoring another subsystem), but the dedicated operator, from his workstation, can have access to more detailed information and operate the system with automation and AI support.

4. Deep analysis, AI and Cognitive Assistant

System supervision and TMS automation greatly ease spacecraft operations. But sometimes automation is not enough and AI is the solution for more complex data, to understand more complex mechanisms and to propose contingency fix procedures.

4.1 Alert solving

Our systems can complete a large diversity of missions, but are also more complex. As seen before, payloads are diverse (optics, SAR), antennas solutions are diverse (local, polar, As a service), and the ground segment infrastructure can be different (private cloud, public cloud). Contingency identification, and delivering the corresponding operational procedure to fix the contingency is becoming very difficult with such complex systems. This is why Airbus and its partners have developed an AI concept which will support the automation. During a contingency, the targeted sub-system will raise an alarm towards the TMS. The automation will display and gather the main data about this contingency. AI will then follow along by digging deeper with more fine data, logs and other sub-systems in order to precisely define the root cause of the root contingency, should it be escalated. AI will then propose to the level-1 operator, through a dedicated interface, an operational procedure to fix this alarm. In certain cases it can propose several procedure with an associated confidence level. The level-1 operator would then decide which procedure to run, or ask for level-2 expert support. The AI will certainly learn from every contingency fix and refine its own propositions. We can therefore expect more human tasks at the beginning of life of the system, and a large AI autonomy while the system is running for some time.

4.2 Contingency anticipation

As seen in section 4.1, AI will propose solutions to fix actual contingencies, and its proposed solutions will be more and more precise. In parallel, the AI will be fed by all the available data, data and contingency history, so it can anticipate and predict future contingencies. We are talking about fine multi-variable multi-sub-systems data analysis, not a simple time-tendency telemetry follow-up. The multi-variable multi-sub-system data analysis allows the finest anticipation for contingencies. It is obvious that learning will take some time, regarding the system complexity. But we can expect some first analysis would be available rapidly after some in-house training at provider facilities before delivery.

5. Human / Machine interaction

As seen previously, spacecraft operations will completely change with the new innovations led by DOMINO-X. Level-1 operator's tasks as we know them today will drastically evolve. Therefore we had to think about human factors such a transformation will disrupt. This is why a special attention has been raised in DOMINO-X for Human/Machine interaction.

5.1 Cognitive assistant

With our partners from cognitive science and AI development, it came out that the AI should be incarnated and supported by a cognitive assistant. It allows to have a more human-friendly interaction and ease to identify from where does an information come from? AI, automation or sub-system itself. It is very important to then decide either to run or not a procedure. The cognitive assistant would allow to support the operator during the procedure run, when proposed by the AI. We can easily imagine that later, when AI is trained, operators would have enough trust in the AI to let it run procedures by itself, while being only as a human support. Time effectiveness and ease in operations have never reached such levels for deep and complex analysis.

5.2 Human factors and room layout

The interaction with the supervision and the general look and feel must evolve to meet current requirements and expectations. The graphical interfaces for the supervision and the operators workstations have been completely redesigned with the human factors in mind (colour coded, pictograms, font size on large displays…). The room layout has also been completely redesigned to meet the new CONOPS challenges.

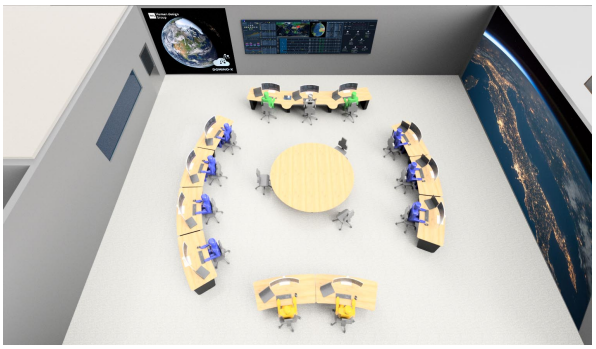

Fig. 3. DOMINO-X control room layout mockup (Human Design Group)

The room layout is therefore optimised to facilitate level-1 operators' tasks and their interaction with the supervision display system. The communication with level-2 experts is also eased thanks to the disruptive room layout proposed by the human factors experts from Human Design Group, partner company of DOMINO-X project. Spacecraft operations are evolving, so must do the room layout.

6. Conclusion

Earth Observation systems can answer more complex and variable needs. But they are themselves complex today. Spacecraft operations must be reconsidered to ensure availability and data access timeliness. The amount of data generated by such system is too important to be analysed by humans. Automation is the first step to gather and analyse these data. Artificial Intelligence can analyse deeper and propose solutions to fix contingencies. It can also anticipate future trends. The CONOPS as we know it today is completely modified. We must then to redesign human/machine interaction. This is what Airbus and its partners have performed within DOMINO-X project to propose today a new way to operate an EO constellation, with a new way of working for operators, while ensuring a high system availability and a precise data follow-up.

In the medium-term future, the ambition is to achieve a "lights-off" centre, where operators will be present only during very specific or critical events. Airbus has always led the space market, and another time today, with strong partners, propose innovations for an Earth Observation Ground Segment that will drastically change spacecraft operations.

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